

Dating of the Sedimentary Cover Reflectors and Evaluation of the Sedimentation Rates in the Late Pliocene–Quaternary in the King’s Trough and Vicinity (the North Atlantic)

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Abstract—Based on the results of the expedition works during the 55th and 57th cruises of the R/V Akademik Nikolai Strakhov in the area of the King’s Trough mesostructural complex (the eastern flank of the MAR), seismoacoustic profiling data of the upper part of the sedimentary cover are obtained. Reference reflectors, which were correlated with the DSDP 608 and IODP U1312 deep-sea drilling holes, are identified from the seismoacoustic sections. The sections cover the entire Quaternary sediment record (glacial cycles) and a part of the Upper Pliocene sediment record. Sedimentation rates within the different structures of the King’s Trough are calculated as a result of the works. During the past 1.5 Ma, sedimentation rates have been slightly different across the study area from background sedimentation rates, while earlier sedimentation rates were recorded to exceed the background ones by several times. There is a period of sharply increased sedimentation rates (up to 180 m/My) at ca. 1.5 Ma, which may be due to abrupt climate changes and ocean level fluctuations. Prior to the onset of the Mid-Pleistocene Transition ~1.5 Ma ago, a bottom current might have flowed along the bottom of the western part of the King’s Trough, which caused high sedimentation rates in the bottom of the trough. The current stopped after the onset of the transition, which could be due to regional restructuring of the Atlantic Meridional Overturning Circulation. These conclusions are correlated with sedimentation rates and changes in ocean surface temperature based on the data from IODP U1313.

Keywords: acoustic profiling, Atlantic meridional overturning circulation, paleocurrents, Mid-Pleistocene Transition, stratigraphic correlation, bottom currents

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INTRODUCTION

The analysis of the spatial distribution of sedimentary cover in the North Atlantic shows based on data [1] that a significant portion of the deep-water area beyond the continental margins (~90%) is covered by a sedimentary layer less than 1000 m thick. Most of abyssal basins and the Mid-Atlantic Ridge (MAR) zone have a sediment thicknesses from 0 to 500 m. These values were obtained by averaging with respect to a large number of route and study area seismoacoustic soundings, which are distributed rather unevenly in space. They have a generalized character, and in reality, detailed surveys (Fig. 1) can evidence significant local deviations from the average thickness values. The sedimentary cover is formed by the superposition of two factors of sediment accumulation, pelagic deposition of material from the water column at rates of 5–15 m/My and deposition from bottom

currents, turbidites, and contour currents [2] at rates of ≥ 50 m/My, which is confirmed in the North Atlantic by deep-water drilling data [3]. A significant contribution to the variation in sediment accumulation rates is also made by a climatic factor, in particular, glacial cycles during the Quaternary, associated with sea level fluctuations [4] and the position of bottom currents in the Atlantic meridional overturning circulation [5].

In the work area (Fig. 1), according to data [6], Arctic waters branch out along the eastern flank of the MAR from north to south, which disrupts the monotonic pelagic increase in sediment thickness orthogonally to the ridge axis. This is seen in the area outlined by the 150-m isopach (Fig. 1) and located along the current trajectories. Additionally, there are also sublatitudinal currents crossing the MAR along the valley of the Maxwell transform fault [5] and the northern margin of the Azores Plateau [7]. According to data [1],

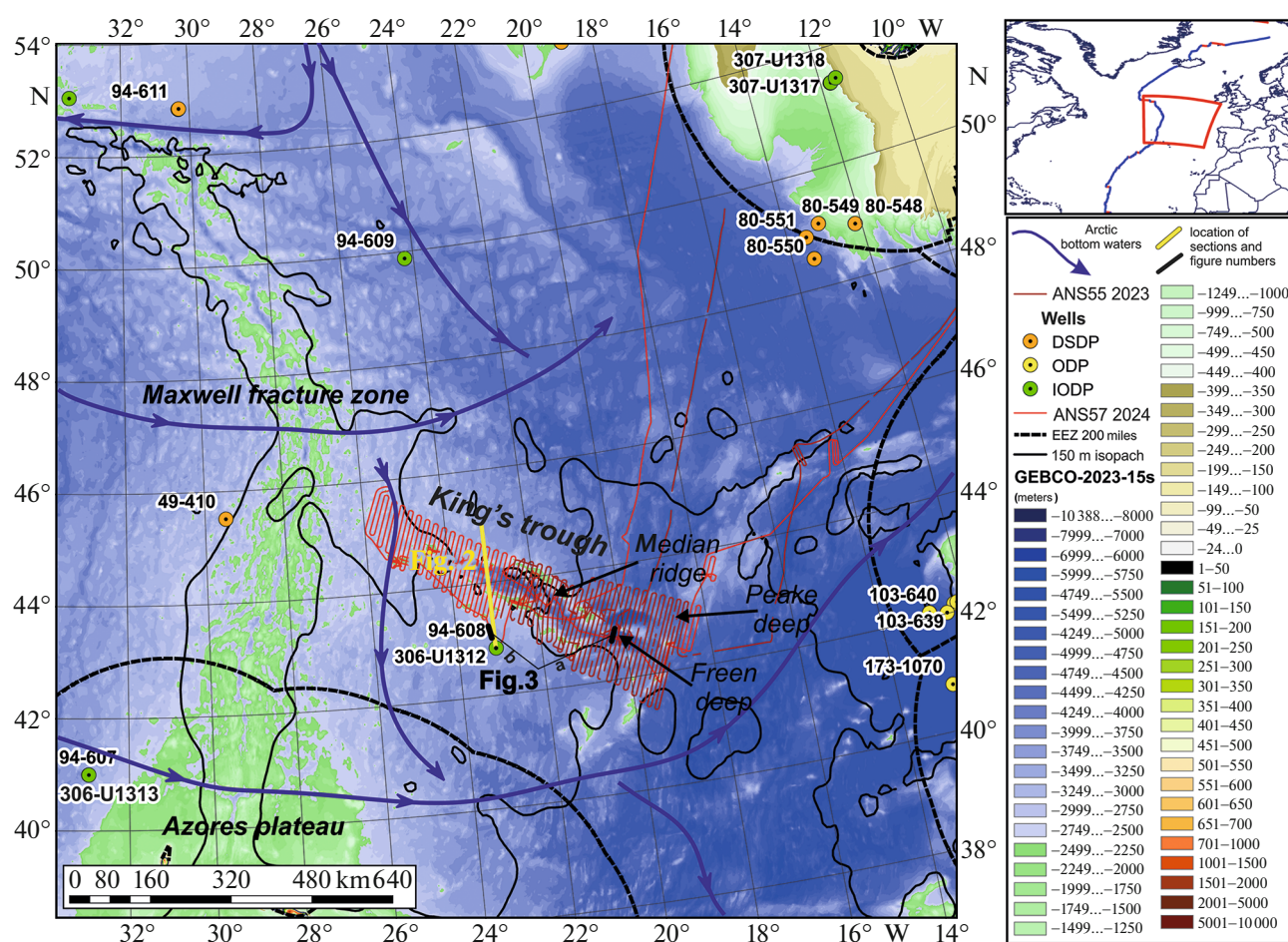


Fig. 1. Location map of the route and study area soundings during the 55th [12] and 57th [13] cruises of the R/V Akademik Nikolai Strakhov (Geological Institute, Russian Academy of Sciences, 2023, 2024) in the King's Trough region (the North Atlantic), schematic movement of bottom Arctic waters according to [5–7], positions of DSDP, ODP, and IODP deep-sea drilling holes, the boundary of the 200-mile exclusive economic zone, and the 150-m isopach according to [1]. The topography is shown based on GEBCO data. Thick black lines and the yellow line designate the positions of the seismoacoustic sections used in this work in the corresponding figures.

sedimentary thicknesses can vary from 500 to 800 m within the area located along the current trajectories and outlined by the 150-m isopach (Fig. 1). It is also known that the branching of the currents into narrow and deep landforms can accumulate significant amounts of sedimentary material within them, like it was for example in the trough of the Vema transform fault, where 483 m of Quaternary deposits were exposed by the DSDP hole 26 [8].

The 55th and 57th cruises of the R/V Akademik Nikolai Strakhov (Geological Institute, Russian Academy of Sciences, 2023, 2024) (Fig. 1) were conducted in the King's Trough area, intersecting DSDP (608 and 608A) and IODP (U1312A and U1312B) holes to assign acoustically stratified records to drilling data. The holes were drilled with a time interval of 22 years at the same place. U1312 was drilled to collect an extended range of data [9, 10]. Anomalies were revealed in the spatial distribution of the sedimentary

stratum. The aim of this work is to obtain the most reliable dates of the identified reflectors under conditions of interruption of their correlation with the hole on the outcrops of the acoustic basement and an effective duration of seismic records no longer than 167 ms, as well as to assess the sedimentation rates during the late Pliocene-Quaternary period in a negative form of the bottom relief with local branching out of the bottom current.

MATERIALS AND METHODS

To analyze the general structure of the sedimentary cover in the study area, continuous seismic profiling (CSP) data were used, which were collected during the preparation for drilling in the DSDP project and were published in their original digital format [11]. To analyze the structure of the upper part of the sedimentary layer section, the data from the 55th [12] and 57th [13]

cruises of the R/V Akademik Nikolai Strakhov (Geological Institute, Russian Academy of Sciences, 2023, 2024) were used. They were obtained using the Parasound P-35 parametric profiler, designed for mapping the structure of the upper part of the sedimentary cover (up to 150 m along a weakly consolidated clay section) with high resolution (from 1 to 10 m in abyssal conditions), and the EdgeTech 3300 high-frequency profiling system with the same specifications.

The seismoacoustic data were processed using SeisPro software (OOO Deko-Geofizika SK, Russia). For the correlation and geological interpretation of the wave field, a survey was made over DSDP 608 (the drilling depth of 530.9 m), 608A (146.4 m), and IODP U1312A (237.5 m), U1312B (231.9 m) holes (Fig. 1). The holes exposed deposits from the Quaternary to the Middle Eocene (~42 Ma), bedded on a basaltic basement at a depth of 517 m (hole 608) [14]. We note that the lithological composition of the hole cores varies significantly: there is a range of values both in depth (within 10 m) and in the sequence of the horizons. This is related to the different lithological classifications adopted in the drilling reports [9, 10] and probably to their near-slope locations, which might have caused slightly different sedimentation rates in the nearby areas due to the slope development. Nevertheless, the lithologies of the hole cores correlate quite clearly with each another.

During the survey over holes 608 and U1312, a seismoacoustic record was obtained at the coordinates specified in the drilling reports [9, 10] during the 57th cruise of the R/V Akademik Nikolai Strakhov [13], which evidently does not correspond to the section from the drilling report. The time section clearly shows chaotic seismic complexes with numerous bright spots, intermittent unclear horizons, and pit-and-mound subhorizontal relief. We assume that a technogenic plowing of the original structure of the upper part of the weakly consolidated sedimentary cover is identified directly above the hole. The data on the southwestern margin of the King's Trough do not have continuous correlation with the deposits in the basins at the drilling point; therefore, the reflectors are compared based on similarities in their geometry, repeatability, and intensity. To perform an analysis, we selected a record fragment of 5 km on a moderately flat seafloor at a distance of ~20 km north of the hole, which has a consistent character of stratification.

RESULTS

General Characteristics

A considerable part of the study area (Fig. 1) represents rises of the acoustic basement with steep slopes without a sedimentary layer (Fig. 2). Continuous sedimentary layers occur on the flanks, in the axial parts of the King's Trough, and in the anomalously deep (up

to 5950 m) basins, which also include the Peake and Freen Deep. A sub-meridional section was constructed through the trough structures according to the CSP data [11] (Fig. 2a). On the northern and southern flanks of the King's Trough (Fig. 2a), the sedimentary cover was established to be 600–700 ms thick. Taking into account the linear gradient of seismic wave velocities in the pelagic sedimentary layer, which is equal to 0.33 s^{-1} [15], and the velocity of waves at the seafloor of 1500 m/s, the thickness of the sedimentary cover ranges from 470 to 560 m, which is within the generalized values for this area [1]. However, there are also local increases in thickness (Fig. 2a): on the southern flank of the trough (up to 700 ms) and in its axial part (up to 900 ms). This may suggest contour currents to be present along the southern slope and bottom currents within the trough. Thicknesses up to 600 ms are preserved but are interrupted by disjunctive offsets on the ridges of the flanks, which may indicate recent movements that formed the modern seafloor topography without the destruction of the weakly consolidated sediments.

The section of hole 608 is one of the most complete intervals of the Oligocene-Quaternary section [9] drilled in the North Atlantic (Fig. 2b). It exposed the Middle Eocene basement. The lower part of the section is represented by zeolitic and foraminiferal chalks. At a depth of 465 m (0.4–0.6 s), a regional hiatus in sedimentation lasting 9 Ma is recorded at the Oligocene-Eocene boundary. One more hiatus is observed at 360 m (0.2–0.4 s) and is identified as Early Eocene. The Late Miocene-Pliocene part of the section is represented by organogenic oozes, while the Pleistocene part includes glacial and organogenic oozes and marls. Glacial cycles in the holes begin at a depth of ~50–80 mbsf. In the Upper Pliocene part of the section, a single turbidite sequence is recorded. It is interpreted as a period of instability in sedimentation on the southern flank of the trough [16].

Analysis of the Upper Part of the Section

The section interval surveyed during the 57th cruise of the R/V Akademik Nikolai Strakhov belongs to the Upper Pliocene-Holocene part of the section (acoustic layers A and B) and is interpreted as glacial and interglacial deposits. According to the CSP data (Fig. 2b), the thickness of the upper seismic complex is 50–100 m. This means that the data from the survey by the Parasound high-frequency profiler characterize the entire Quaternary section and a large part of the Upper Pliocene section, with the maximum effective duration of the seismic records.

The upper layer of the sedimentary cover, which can be reflected in the profiler records, is represented in the hole by glacial and interglacial series, including alternating nanofossil oozes, nano-foraminiferal oozes, and marly nano-foraminiferal oozes with single

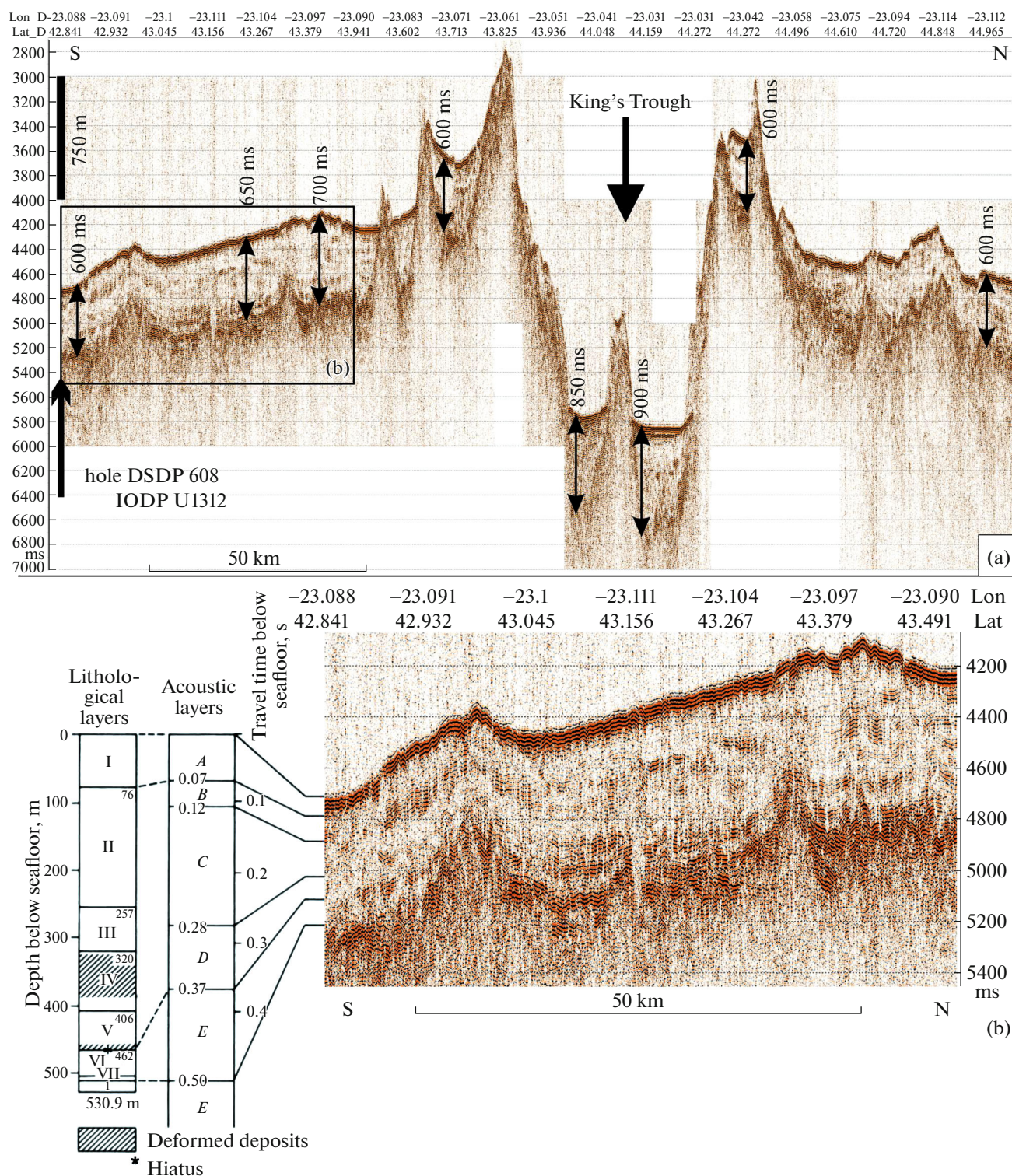


Fig. 2. (a) CSP section compilation based on data from [11]. Position of the section is shown in Fig. 1. Oppositely directed arrows show the estimates of variations in sedimentary cover thicknesses in ms; (b) CSP section combined with lithological subdivisions of hole 608 [9]. The Upper Pliocene-Quaternary part of the section corresponds to lithological subdivisions I, II (upper part) and acoustic subdivisions A and B [16].

nano-foraminiferal sands and signs of active bioturbation [9, 10]. They significantly differ in the content of silt and clay fractions, which varies from 0 to 60%. The considerable lithological differences disappear at

depths from 45 to 65 m. Underneath is the beginning of an almost homogeneous sequence of nanofossil oozes, which is beyond the possible survey range of the profilers (Fig. 3).

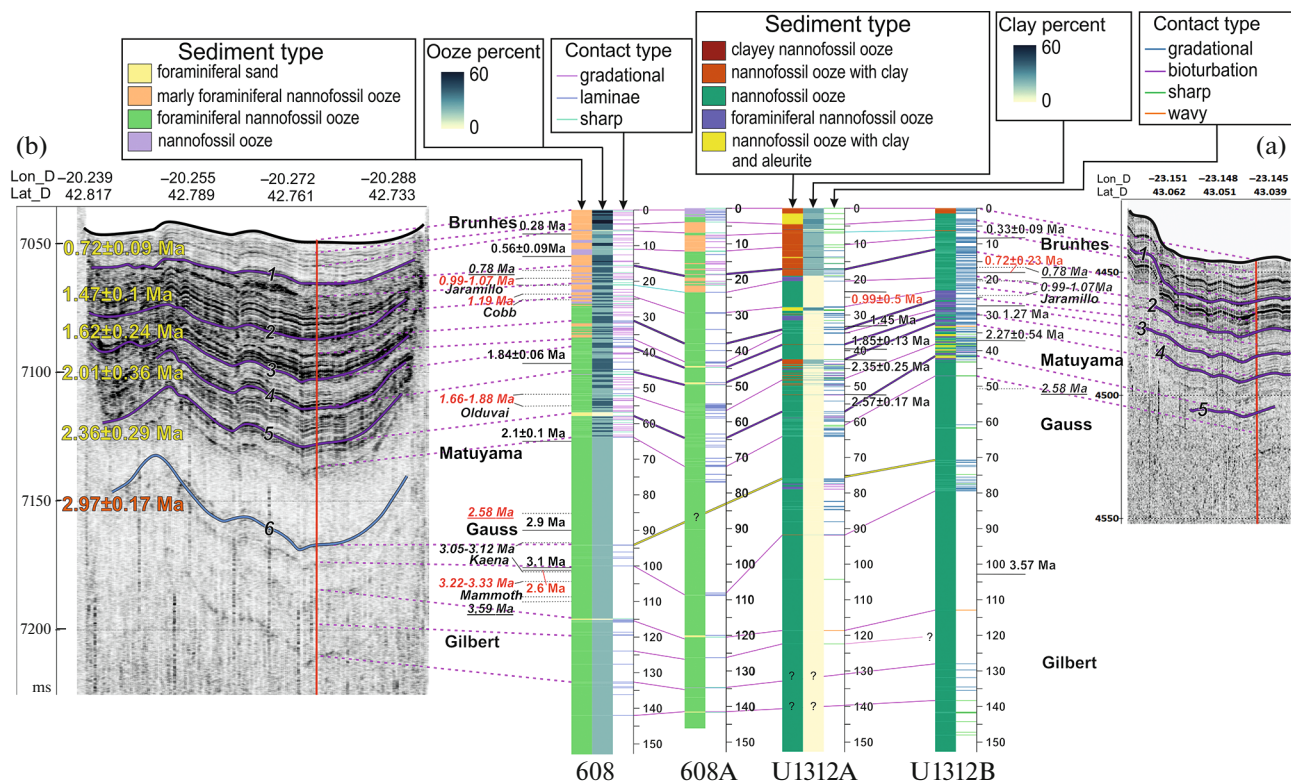


Fig. 3. Correlation of the sections from Parasound P-35 high-frequency profiler (a) in the vicinity of holes 608 [9] and U1312 [10] and (b) in the Freen Deep across survey line 16 of the 55th cruise of the R/V Akademik Nikolai Strakhov with hole material, paleomagnetic (italic) and biostratigraphic (upright font) data. Unreliable dates are highlighted in red.

The correlation of the seismoacoustic section with drilling data was conducted based on the nearest stratified section (Fig. 3a), located ~20 km northwest of the hole (Fig. 1). This section also correlates well with other seismoacoustic sections within the study area along the reference horizons, particularly with one of the deepest (167 ms) and most detailed sections through the Freen Deep (Fig. 3b), which was also correlated.

Reference reflectors were identified in the seismoacoustic record based on their most frequent occurrence among other profiles from the study area survey (Fig. 1) and their intensity. The upper three reflectors are clearly traced across all survey lines of the study area, both among the sedimentary sections of the basins and the flank structures. The correlation of the main and additional reflectors with the drilling data was made based on several stratigraphic features: differences in the lithological compositions of the rocks, the proportion of silt and clay material, as well as the type of boundaries between the layers.

The reflectors were dated based on correlation with paleomagnetic and biostratigraphic markers by their average values for four holes [9, 10]. The 1σ interval was accepted as an age error. Since the sedimentation rates were apparently unstable and varied throughout the Pliocene-Quaternary, only rough estimates of the

reflector ages can be provided here. Nevertheless, we can say with reasonable confidence that the seismoacoustic record of most sections covers at least 2 Ma, and the age estimates are reliable within the error. In the hole vicinity, the time section almost corresponds numerically to the depths of the layers in the hole, which indicates a relatively high sediment density. This agrees with the bottom sampling data in the King's Trough basin during the 57th cruise of the R/V Akademik Nikolai Strakhov [13].

DISCUSSION

Based on the obtained results, we calculated the sedimentation rates for 33 points located in the basins of the King's Trough and within its flank structures (Fig. 4). The rates were determined during six time slices in the parts of the seismoacoustic profiles that are least disturbed by faults in the central areas of the basins.

During the first two time slices (0–0.72 and 0.72–1.47 Ma, Figs. 4a, 4b), the sedimentation rates in most of the territory are within the background values for pelagic conditions [2]. Few increased values are associated with the local development of submarine landslides. There are somewhat higher values on the southern flank of the trough compared to the northern

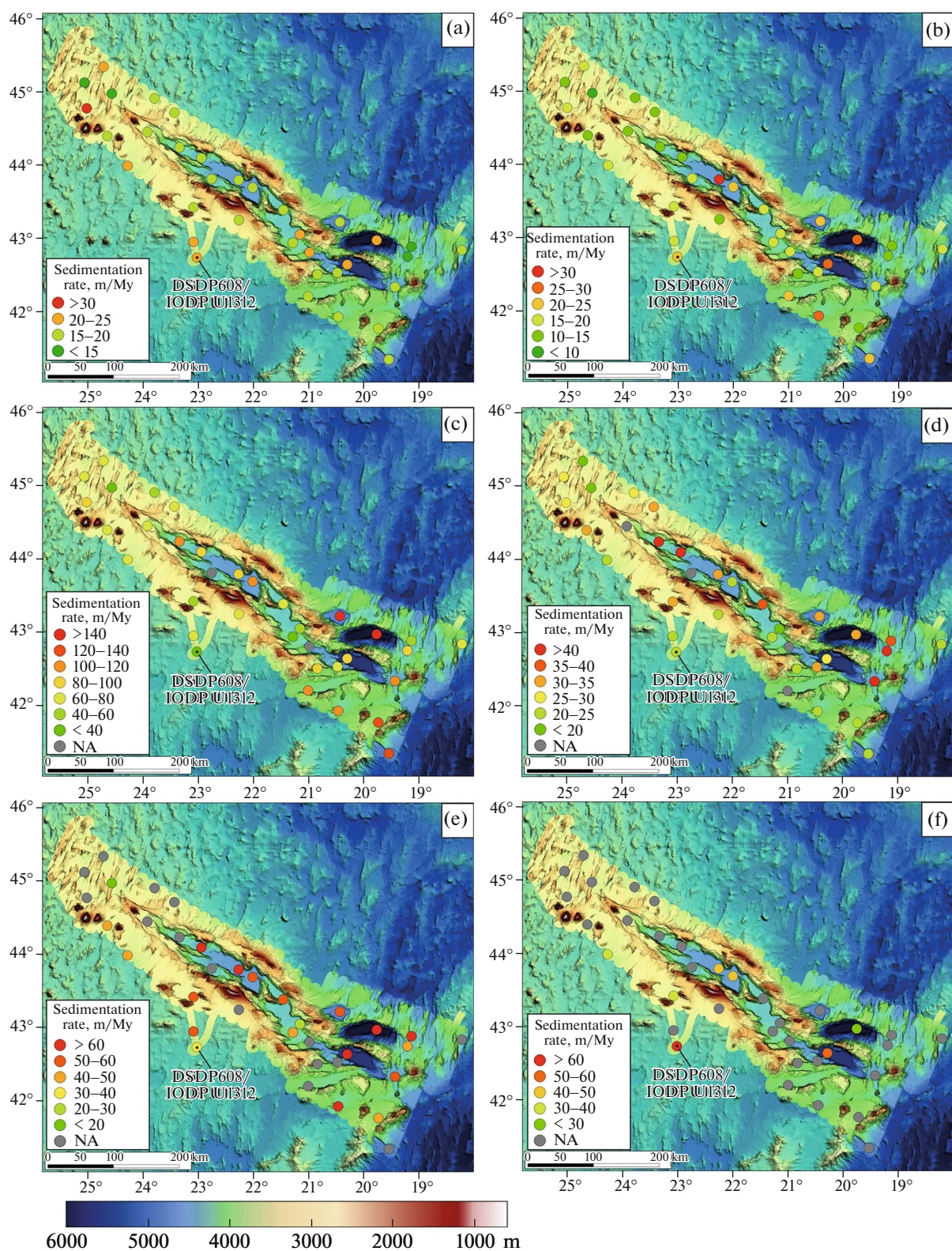


Fig. 4. Sedimentation rates within different morphostructures of the King's Trough: (a) 0–0.72 Ma; (b) 0.72–1.47 Ma; (c) 1.47–1.62 Ma; (d) 1.62–2.01 Ma; (e) 2.01–2.36 Ma; (f) 2.36–2.97 Ma.

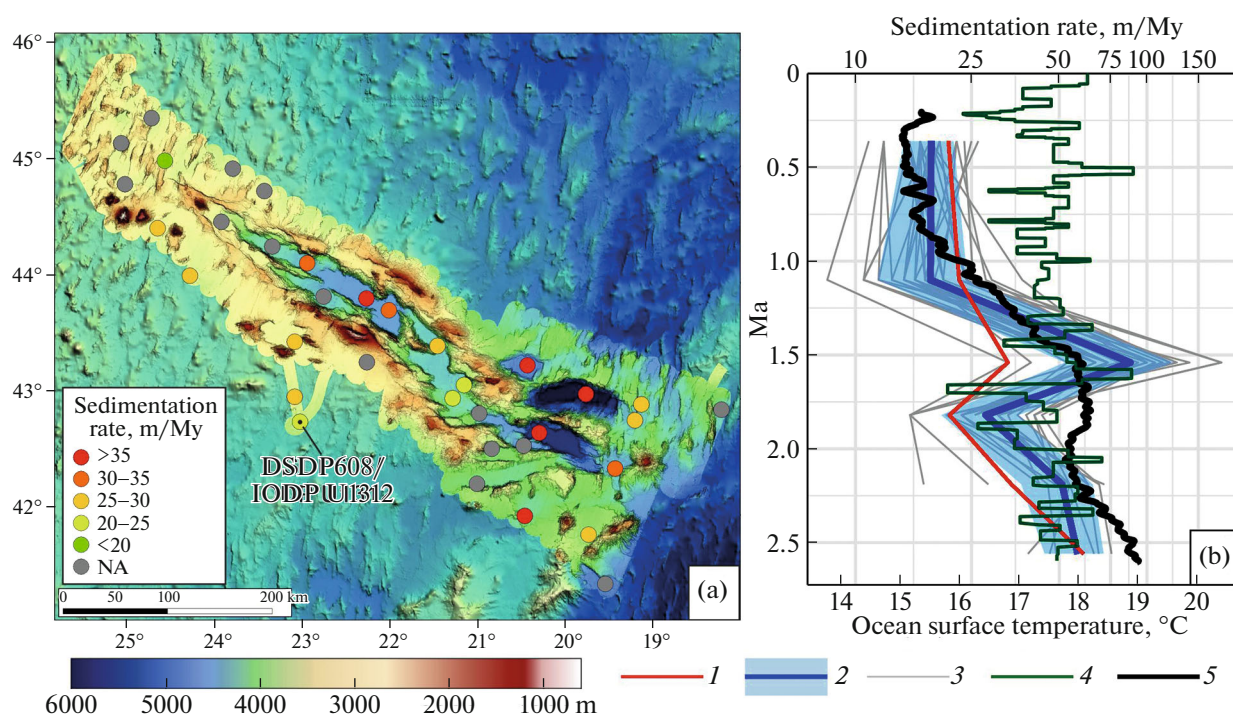


Fig. 5. Sedimentation rates: (a) within different morphostructures of the King's Trough from the beginning of glacial-interglacial cycles (2.36 Ma – till present); (b) average rates across time slices corresponding to the dated reflectors. 1, Average rates derived from holes 608 and U1312; 2, average rates within the study area and their root-mean-square deviations; 3, rates from individual points within the study area; 4, rates from hole 607/U1313 on the western flank of the MAR; 5, changes in ocean surface temperature based on fluctuations in organic content in hole 607/U1313. Smoothing using a 400 kyr moving window [18].

flank, which is also consistent with CSP data and suggests the contour current to be present along the southern flank at the current stage of development. In addition, slightly increased values are recorded in the eastern part of the study area (the Peake and Freen Deeps), which may possibly be due to the absence of ridges along their sides, which could not allow the influx of sedimentary material into the King's Trough basins. The high values in the eastern part are in general preserved throughout the Quaternary period (between reflectors 1 and 5, up to 2.36 Ma, Fig. 5a). The calculated rates agree well with the similar values obtained from $\delta^{18}\text{O}$ changes during the past 300 kyr in hole U1312 [17].

The older time slices (Figs. 4c–4e) show significant differences in the western part of the King's Trough basins (up to the Median Ridge), where increased sedimentation rates are recorded compared to the flank structures. In this case, the sedimentation rates remain significantly lower to the east of the Median Ridge. This may indicate the presence of a paleocurrent that flowed along the bottom of the King's Trough from west to east until the beginning of the Middle Pleistocene and stopped at the foot of the Median Ridge, which acted as a barrier.

The average sedimentation rates also attract the attention (Fig. 5b): they were still increased (from the

holes and along the profiles) during the Late Pliocene–Early Pleistocene (up to ~1.5 Ma), but decreased afterwards to the values that only slightly exceeded the background ones. However, the peak sedimentation rate was recorded around 1.5 Ma, which was traced by profiling data (up to 180 m/My), although it was significantly less pronounced according to the drilling data. In this part of the section (the Upper Pliocene – Lower Pleistocene), the sedimentation rates correlate well with the rates from hole IODP U1313 (at the site of hole DSDP 607) on the western flank of the MAR (Fig. 1, Fig. 5b) [18]. This hole also shows increased sedimentation rates and the peak rate around 1.5 Ma. This suggests that a similar peak does indeed exist in the King's Trough region and is not an error in data interpretation. The onset of the Middle Pleistocene transition (or revolution), marked by a sharp rise in the sea level and a gradual restructuring of glacial-interglacial cycles, is dated approximately to this time [19, 20]. Besides, erosional hiatuses in marine sediments of Western Iberia are dated exactly to this period [21], which evidences the intensification of erosional processes. This event might have affected the sharp increase in the sedimentation rates on the eastern flank of the MAR.

In the Middle Pleistocene–Holocene, the sedimentation rates in the study area and in the vicinity of hole U1313 began to differ significantly: in the latter

case, the sedimentation rates were still increased [18], while in the study area, they approached the average values (Fig. 5b). We believe this was caused by the termination of bottom current in the western part of the King's Trough, while currently it flows in the vicinity of hole U1313 and is the branch of the Atlantic Meridional Overturning Circulation [7]. The sedimentation rates in the study area correlate well with the trend of paleotemperatures of the ocean surface from hole U1313 (Fig. 5b), which is located only 2° southward. This likely indicates a decrease in the average sedimentation rates due to the decrease in temperature during the Pliocene-Pleistocene climate changes. The onset of the Middle Pleistocene transition might have led to a restructuring of the entire system of bottom currents in the Atlantic Meridional Overturning Circulation, which resulted in the disappearance of the branch at the bottom of the King's Trough.

CONCLUSIONS

Based on the results of processing of the acoustic profiling data in the King's Trough region and its vicinity and the subsequent correlation of the sections with the deep-sea drilling holes, the sedimentation rates within the study area were determined during six time slices. The following conclusions were made.

(1) The thicknesses of the composite section of the sedimentary cover on the southern flank and in the basins of the King's Trough exceed such values on the northern flank, which may indicate the presence of contour and bottom currents. This is also confirmed by the analysis of sedimentation rates during the Quaternary period.

(2) Two stages of Late Pliocene-Quaternary sedimentation are established: the first (up to ~1.5 Ma) is characterized by the increased sedimentation rates, while the second stage, ongoing currently, has sedimentation rates that are close to the background levels.

(3) Before the onset of the mid-Pleistocene climate transition, a current, which was a branch of the Atlantic Meridional Overturning Circulation, was likely to flow along the bottom of the western part of the King's Trough. The change in the system of bottom currents correlates with global climate changes, sea level rise, and intensified erosion within Iberia, the nearest dry land to the study area.

(4) The identified fluctuations in the sedimentation rates agree well with temperature variations in the North Atlantic during the Late Pliocene-Quaternary period and evidence a decrease in the sedimentation rates at a decrease in temperature.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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